# Plan to Present a Consistent Beam Flux in the DUNE CDR

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This document summarizes discussion among the conveners of the Long-baseline Physics, Systematics, and Beam-Requirements Task Force conveners ("LBL conveners") and presents a plan to use a consistent beam reference design in the LBNF and Physics sections of the DUNE CDR. This plan has been agreed upon by the LBL conveners but given how fundamental the choice of beam reference design is to the experiment and the coordination that is required with the project team, we would like to have this plan approved by collaboration leadership.

## The issue

The LBL conveners want to choose a single beam design to use for physics sensitivity studies presented in the CDR, as we understand that use of multiple beams in previous documents has been a source of confusion for some readers. We have the following primary criteria for choice of beam reference design:

- The beam flux used for physics studies should be consistent with what is presented in the LBNF section of the CDR. We believe that continuing to use a significantly different beam design for physics studies from that which is presented in the cost/schedule analysis is not appropriate for the CDR and would be a weak point in the CD1 review.
- The beam flux used for physics studies should be one which yields adequate sensitivity to MH and CPV determination. We do not wish to present sensitivities that are marginal and do not accurately reflect the physics potential of the DUNE experiment.

There is some conflict between these two objectives as the beam flux resulting from the reference design described in the LBNF section is known to have significantly worse performance than the beam flux that has been used for physics studies in previous documents, including the LBNE Science Book and the ELBNF LOI. Table 1 compares features of the reference design and the "80-GeV" beam that was used for the nominal sensitivities in the LOI.

Table 1: Summary of design choices in LBNF Reference beam and the "80-GeV" beam that was used for LBNE Science Book and ELBNF LOI physics studies.

| Feature | LBNF Reference Beam | "80-GeV" Beam |
|---|---|---|
| Proton Energy | 120 GeV | 80 GeV |
| Target Distance from horn 1 | -45 cm | -25 cm |
| Horn Current | 200 kA | 230 kA |
| Decay Pipe Diameter | 4 m | 6 m |
| Decay Pipe Length | 204 m | 250 m |
| Decay Pipe Atmosphere | Helium | Helium |

## Proposed Solution

It is our understanding that the option of a 250-m decay pipe, while not the reference design choice, will be discussed in the LBNF section of the CDR. This choice alone yields $> 10\%$ increase in the $\nu_e$ appearance event rate at an estimated cost of $30M. We consider the choices of horn current and proton beam energy to be operations choices rather than design choices given that the reference design is capable of running in these conditions and that there is not expected to be additional project cost arising from these changes. The higher horn current yields an additional $> 10\%$ increase in the $\nu_e$ appearance rate and the lower proton energy reduces background. As these three improvements have been studied by the beams group, are expected to be described in the LBNF section of the CDR, and have known cost, we propose using an "enhanced reference design," which is based on the reference design but includes these improvements, for sensitivity studies in the Physics section of the CDR. To be explicit, the beam flux used for physics studies will be based on the following design/operations choices.

- Proton energy: 80 GeV
- Proton beam power: 1.07 MW (maximum power at 80 GeV)
- Target material: graphite
- Target distance from horn 1: -45 cm
- Horn current: 230 kA
- Decay pipe diameter: 4 m
- Decay pipe length: 250 m
- Decay pipe atmosphere: Helium

The flux resulting from this beam design will be simulated and used for all physics sensitivity and systematics studies. The exception to this rule is that the "Beam Requirements" section of the CDR will describe the effect, both on flux shape and physics sensitivity, of varying parameters within the NuMI design as well as optimizing the focusing system further by considering alterations to the focusing geometry outside the NuMI design. Note that such modifications to the focusing system will likely require an extension of the target chase by ~6-8 m.

We have considered the time requirements for producing the studies required by this plan and are confident that this can be done carefully and correctly on the timescale of the CDR.